2020

The Effect of Time and Temperature on the Quality of Latent Fingerprints on Incandescent Lightbulbs, Varying Donors Age and Sex

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The Effect of Time and Temperature on the Quality of Latent Fingerprints on Incandescent Lightbulbs, Varying Donors Age and Sex

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Forensic Science at Virginia Commonwealth University.

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November, 2020

ACKNOWLEDGEMENTS

I would like to express my gratitude to Dr. Tal Simmons Ph.D., for giving me the opportunity to perform my directed research project in her laboratory and for serving as my research advisor. Her enthusiasm, guidance, expertise and patience to all my questions certainly helped me through the project. I would also like to thank Janine Sodano, M.S., for her fingerprint's advice, guidance and help; Dr. D'Arcy Mays Ph.D. for his great help in employing statistical tests and their analysis; and Stephanie Walcott, M.S., for her great encouragement. Thank you all for serving as my committee members during this interesting project.

This project was also possible thanks to Olivia Colella, whom previous research and advice motivated this study. Thanks to Jo Murphy for helping me find potential fingerprint donors during the campus phased reopening and Dr. Marilyn Miller for collaborating with fingerprint lifting materials. Thanks to Ramont Reed and Logan Bishop from the VCU IT team for helping me in the software installation processes; John Arnold for the electrical modifications to the units; and Dr. Christopher Ehrhardt for his teaching and advice on statistics. Special thanks to Tal, John and Matthew Adreance for serving as fingerprint donors.

Finally, thanks to my caring family and friends for their love and support during challenging times, your encouragement and support have helped me achieve so much.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

THE EFFECT OF TIME AND TEMPERATURE ON THE QUALITY OF LATENT FINGERPRINTS ON INCANDESCENT LIGHTBULBS, VARYING DONORS AGE AND SEX

By Kinaysha Mar Collazo Maldonado, B.S.

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Forensic Science at Virginia Commonwealth University.

Virginia Commonwealth University, 2020.

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Fingerprints are used as a means of identification, but there are no established methodologies to determine time since deposition of latent fingerprints by visual means alone. This research considered the influence of age and sex on the quality of recovered latent prints from lit and unlit lightbulbs from 1 to 10 days, using accumulated degree hours (ADH) to account for both heat and time simultaneously. Two male and two female donors (one of each aged <40 and >40 years) were used. A thermal imaging camera was used to monitor the lightbulbs top and middle regions, which were significantly different ($p \leq 0.05$) for the experimental and control lightbulbs. The recovered impressions were evaluated using a quality score scale from 0-5. After studying the quality scores over days lit and ADH, we found they started with good quality, decreased, remained constant and then began to randomly fluctuate. The analysis of covariance for both the lit and unlit lightbulbs showed that sex ($p \leq 0.001$) and experimental versus control lightbulbs ($p \leq 0.001$) may have an influence on the latent print quality, but not ADH ($p \leq 0.281$) or age ($p \leq 0.242$). This research supports the long-held conviction of latent print examiners that the age of a latent print cannot be determined by visual assessment alone. More research is still needed to provide a broader understanding of how latent fingerprints are affected by both environmental conditions and donor variability. These factors can be crucial in court for the deliberation of criminal cases relying on impression evidence.

Keywords: Latent fingerprints, impression evidence, ADH, quality score

INTRODUCTION

Fingerprints are commonly used for identification purposes, but there are no established methodologies to determine time since deposition of latent fingerprints by visual means. Several studies considered different types of fingerprint depositions, substrates and lighting conditions using a single donor over a lengthy exposure time (1-4) but did not consider factors of heat or donor variability. Chemical methods have been used to examine the degradation of latent fingerprints in an effort to age them, but they require specialized instrumentation and expertise (5). Likewise, there is no published literature addressing the effects of sex or age affect the composition and amount of skin secretions, which may in turn affect the quality of recovered latent fingerprints. This research considered the influence of age and sex on the quality of recovered latent fingerprints from lit and unlit lightbulbs during short exposure times, measured in accumulated degree hours (ADH). The purpose is to explore possible relationships between age and sex with respect to the latent print's quality over ADH, to determine whether visual patterns of degradation are present.

Traditional incandescent lightbulbs are a source of artificial illumination. In this type of lightbulb, current passes through a tungsten filament surrounded by an inert gas such as nitrogen or argon, increasing the filament temperature and emitting light energy (6). Incandescent lightbulbs are the cheapest and most accessible on the market, but they are not the most energy efficient. Incandescent lightbulbs consume more watts of energy than other lighting alternatives to produce the same amount of light or lumen, wasting energy and money. In 2007, the United States enacted the Energy Independence and Security Act to set restrictions on the maximum power consumption on general lightbulbs (7). This implementation was delayed for several years due to funding restrictions, but eventually took place and reflected on the ban of most incandescent lightbulbs. By this time, energy efficient lighting alternatives like halogen lamps, fluorescent lamps and LED's became the most popular. However, in September 2019, the Trump Administration rolled-back these energy efficiency standards for lightbulbs and withdrew other restrictions that would have taken place on 2020 (8). This measure made incandescent lightbulbs again the most common, cheap and accessible within the USA.

The ubiquity of incandescent lightbulbs on almost every space that uses artificial illumination makes them likely to be found on crime scenes as a potential evidence source, particularly for latent fingerprints. Latent fingerprints can be deposited on lightbulbs during their intentional or accidental removal, replacement, or maintenance. For example, a criminal might remove a lightbulb to ensure he/she is not seen, as seen on previous cases (4, 9-10). The glass surface from the lightbulbs is made of soda-lime glass, which is also used for multiple surfaces and objects commonly found on crime scenes like drinking glasses, bowls, decorative objects, and bottles.

Fingerprints are a common source of impression evidence and they are often used for identification purposes. Human palms, fingertips on the hands and feet contain friction ridge skin. This type of skin is particular because it has ridges, furrows, pores, no hairs, no oil glands and a high number of nerve endings. Friction ridge skin is also unique and permanent. The details or minutiae found on it are completely formed by the 16^{th} week of embryonic development, which is different for every human. It is also permanent becomes its set from before death until after death, unless profound cuts damage the internal layers of the skin. Pores on the friction ridge skin are connected to eccrine glands, a sweat gland present on all the body but with the highest density on the palms and soles. These pores are constantly secreting perspiration. Sweat is mainly composed of water, amino acids, salts and lipids; lipids include fats, oils and waxes (11).

There are three main types of fingerprint impressions in forensic science: latent, patent and plastic. Latent fingerprints impressions are mostly invisible to the naked eye and need development techniques to be visualized. Patent impressions are two dimensional and visible without development. Plastic impressions are three dimensional and are caste in soft materials. However, latent prints are not the same as latent print residue. Latent print residue may contain sweat, face and scalp oil secretions (from sebaceous glands) and anything in contact with the friction ridge skin, like food or lotion.

Impression evidence can be deposited on different types of surfaces, including porous, semi-porous and non-porous. Porous surfaces are permeable and absorb moisture, semi-porous surfaces can both resist and absorb moisture, and non-porous surfaces are soft and do not absorb moisture. The glass envelope of lightbulbs is made of glass, which is a non-porous surface. Powder processing techniques are the preferred method employed to recover latent fingerprints on non-porous surfaces, which adheres to the moisture on the impression. For lifting latent fingerprints from curved surfaces, e.g., steering wheels, doorknobs and lightbulbs, common lifting materials such as lifting tape are used.

One of the first studies on latent fingerprint degradation was conducted by Alcaraz-Fossoul et al. (1). Alcaraz-Fossoul and co-authors also published other studies using four visual parameters that could relate to the degradation processes of latent fingerprint patterns over time, including the minutiae count, color contrast between ridges and furrows, ridge discontinuities and ridge width (2). They used sebaceous and eccrine secretions on glass and plastic substrates under different light parameters (dark, shade and natural light conditions), in an attempt to identify degradation patterns related to time since deposition (1). Overall, they found that fingerprint degradation was less on glass than on plastic, and that dark conditions somehow accelerated the degradation (2,3). Even though the initial degradation patterns indicated more research was needed, the studies had some limitations: (a) they did not consider environmental factors, e.g., heat on the surfaces; (b) they used titanium dioxide visualization on light surfaces, which is meant to be employed for dark surfaces; (c) they had subjectivity problems due to using one single donor, a male aged in his thirty's; and (d) they only explored long exposure times (1 to 170 days, in seven days intervals).

Few studies have been conducted concerning the impact of environmental conditions on latent fingerprint quality, including surfaces exposed to heat settings (4). Colella et al. (4) studied the effect of time and temperature on the quality of latent fingerprints, using the glass surface of lit incandescent lightbulbs. The surface temperature of the lightbulbs varied by three different regions: top, middle and base. The minimum and maximum temperatures for each region of the lightbulb were measured with a thermal imaging camera each hour for fifteen hours. Those temperatures were averaged for each region, which were: 156.3 °C on top, 112.6 °C on the middle and 62.7 °C on the base. Accumulated degree hours (ADH) represented the average temperature for each region of the lightbulb multiplied by the hours the lightbulbs were on. ADH is used in entomology and anthropology to consider both heat and time exposure simultaneously. The fingerprints were given quality scores, based on the Scientific Working Group on Friction Skin Analysis (SWGFAST) guidelines (4), on a scale from zero to ten, obtaining the lowest average score of 3.3 on top and the highest average score of 5.6 on the middle. For this study, no patterns relating the quality of the print were found, which suggested there is no way to estimate fingerprint age based on its quality after heat exposure. Some of the drawbacks of the study were that: (a) they used one single donor, a female aged in her twenty's; and (b) only long exposure times were used (18 hours and 2, 3, 5, 7, 14, 21 and 28 days).

Hinners et al. (5) published a study on determining the fingerprint age with mass spectrometry imaging. They observed various lipids abundance over time to establish time since deposition for fresh fingerprints and fingerprints developed with carbon forensic dusting powder. They found that unsaturated triacylglycerols decreased over time, but because they were dissociating in room conditions, other two lipid compounds emerged, and their concentrations increased over time. Their study was done with various donors and using short exposure times (1 to 7 days) and found a potential method to age prints. The downside of this method is that expertise in chemistry, expensive and specialized instrumentation is required.

It has been difficult to identify concrete visual patterns for latent fingerprint degradation on glass surfaces, and this becomes even more complicated when introducing other conditions. It is important to highlight that Alcaraz's and Colella's efforts aimed to develop guidelines for crime scene technicians and fingerprints analysists to help determine degradation patterns, or time since deposition, by using only visual means. This study seeks to incorporate several donors of different sexes and ages, since donor characteristics may affect the quality of the recovered fingerprints. Involving multiple donors will allow an evaluation of whether donor's characteristics, which may relate to rate of sweat, composition of secretions and health status affect fingerprint degradation patterns (1).

Currently, there is no consensus about whether sex, age or even ethnicity affect the amount and composition of skin secretions. Shetage et al. (12) used gas chromatography and mass spectrometry to analyze fingerprint impressions from multiple donors and determined these previous factors had no significant impact on the quantity of recovered secretions. Modi et al. (13) found that aging results in loss of collagen, which loosens and dries the skin, affecting the fingerprints quality obtained on biometric scanners. Galbally et al.'s (14) study with over 400,000 fingerprints from donors of 0-25 years and 65-98 years showed that a fingerprint's quality decreases over a person's lifetime. These researchers estimated that somewhere between 25 years and 65 years the fingerprint quality starts to decrease, particularly around forty-three years of age. Given that there is no general agreement as to when the fingerprints quality start to decrease, two age categories are proposed for the donors of this study: "less than forty years" (< 40 years) and "greater than forty years" (> 40 years).

A literature review found no studies on degradation patterns of sex-specific latent fingerprints. However, one study used fingerprint ridge count and fingertip size to classify the sex of a person (15). The ridge number in a fingerprint doesn't depend on age, but they do grow further apart with an increasing age as the body size increases (16). Since males have larger body size than females, the equal number of ridges on a larger surface area means males have a lower fingerprint ridge density (16). Given that physical differences exist between female and male fingertips, we want to study if there are also physical differences on how these two degrade, which is why two female donors and two male donors, one in each age category, were used in this study.

In this study, Colella's (4) experimental setup and ADH variable will be used to study the effects of time and heat on latent fingerprints. The National Institute of Justice (NIJ) has supported research on environmental factors, like heat, affecting impression evidence (17). Considering Colella's results, only the lightbulb regions with the higher and lower quality scores, which are the lightbulbs middle and top regions, were used to consider the effect of heat on the print's quality over time. Shorter exposure times were also considered, to monitor the degradation process closely and to understand fingerprint trace component behavior with the naked eye (4).

The quality of the recovered impressions will be evaluated adopting a ridge quality system published by the National Institute of Standards and Technology (NIST) in 2013. The NIST administers the Organization of Scientific Area Committees (OSAC) for Forensic Science in the United States (18,19). This committee promotes the topic of "Fingerprints and pattern evidence", which publishes studies to aid scientists to perform more accurate fingerprint analysis. Chapman et al. (20) in NIST's special publication "Markup Instructions for Extended Friction Ridge Features" contains a "Ridge Quality Map Values". This map defines the ridges values from zero to five, by describing the ridges, minutiae and pores quality. The scale was applied to the overall recovered fingerprint impression, following the descriptions for the ridges as [0] background, [1] debatable ridge flow, [2] definitive ridge flow, debatable minutiae, [3] definitive minutiae, debatable ridge edges, [4] definitive ridge edges, debatable pores, and [5] all features definitive

(Figure 1). Even though the assessment of the fingerprint impressions quality is subjective, the adopted guidelines are not.

One of the most common forms of evidence investigators may detect and collect at a crime scene is impression and pattern evidence (21). It was expected that incorporating age, sex and time/temperature variables into the experiment might elucidate patterning among these variables that relates to the degradation of fingerprints on glass surfaces.

RESEARCH MATERIALS & METHODS

For this experiment a total of ten cohorts were used, each one representing one day lit from 1-10 days. Each cohort was composed of 10 lightbulbs (Figure 2). For each cohort, 5 lightbulbs were assigned to each age category: < 40 years (female 23 years, male 23 years) and > 40 years (female 58 years, male 45 years). For each age category four lightbulbs were lit and one, the control, remained unlit; two of the experimental lightbulbs were used for the female and two for the male donor in each cohort. For the experimental lightbulbs, each donor placed two fingerprints on top and two on the middle of each bulb. For the control lightbulb, each donor placed one fingerprint on top and one on the middle (Figure 3). In other words, for the experimental lightbulbs each donor had four replicate fingerprints for each region of the lightbulb. For the control lightbulbs, each donor had only one fingerprint on each region of the lightbulb. Thus, each cohort consisted of 40 impressions, which makes a total of 400 impressions for the 10 cohorts. The 320 experimental impressions and 80 control impressions were recovered using "Evident black fingerprint powder", a fiberglass brush and lifting tape.

Experimental design and methodology

In this study, latent fingerprints were deposited on incandescent lightbulbs to study the effect of heat. The lightbulbs used were Sunlite® Clear Medium base appliance lamp of 60 watts and 130 volts. Three refurbished units (A-C) previously installed on two wood pallets with socket connections for ten lightbulbs each, from Colella's study (4) were used (Figure 4). The units were positioned on the floor to prevent temperatures gradients during the experiment. Average room temperature (±0.21 °C) was monitored throughout the experiment using the HOBO® Water Temp

Pro v2 (U22-001) close to the working area. The HOBO Coupler (Coupler-C), HOBO Waterproof shuttle (U-DTW-1), and HOBOware® were also used.

The Portable Thermal Imaging Camera FLIR® Systems T630sc, model T630SC 45° (±1°C) was used for several tests and to monitor the lightbulbs temperatures during the experimentation period. Temperature tests were performed on one unlit lightbulb for 16 hours and one lit lightbulb for 24 hours, monitoring the temperature on top and middle regions every thirty minutes; this also allowed the determination of how long it took for the lightbulbs to reach the average maximum temperature and the time it took to cool down to room temperature. For both cases, the rest of the unit followed the same format previously described: 2 lightbulbs unlit and 8 lit. The average temperatures from the top and middle regions for both the lit and unlit lightbulbs were used as references for where to place the camera points to monitor the lightbulbs temperature during the cohort's experimentation.

The lightbulbs were cleaned with pure ethanol and dried with Kimwipes™ before depositing fingerprints, to remove any dust and previously deposited fingerprints during the handling process. Donors washed their hands and air dried. They touched their fingertips to their foreheads, side of their nose or hairline to redistribute oils prior to depositing the prints using medium pressure. All the fingers except the pinky finger were used, to mimic the fingers that would be used in a natural grab position. A trademark on the top region was avoided when depositing the fingerprints. The experimentation period started the same day the fingerprints were deposited.

In cohort 1 (1 day lit) on one unit, every lightbulb's average temperature on the top and middle regions was monitored every 15 minutes. Once it was determined that the temperatures remained stable, only a few lightbulbs' temperatures from each unit had to be monitored for deviations during the experimentation periods when using up to three units simultaneously. The recorded temperatures were averaged for each region and for each cohort to calculate accumulated degree hours (ADH).

The fingerprint recovery process started on the same day the period finished, after the lightbulbs cooled down. Used gloves when performing the recovery process directly from the lightbulbs connected to the sockets, to prevent fingerprints contamination or additional fingerprints. Labeled the lifting cards beforehand with the recovery date, cohort number (1-10), unit letter (A-C) and socket number (1-10). Each card holds up to four lifted fingerprints, each one labeled (a-d) indicating the lightbulb region from which it was recovered (Figure 3). Removed the lightbulbs from the sockets and placed them in their previous packaging to dispose of in the regular trash. If broken, they were wrapped in paper and then disposed of. All the sockets were cleaned with ethanol before placing new lightbulbs in. Each lifted print was photographed using a Leica M165 C stereomicroscope with the Leica MC170 HD camera attachment, as well as the Leica Application Suite (LAS) version 4.7.1. program. Minutiae were marked on the recovered fingerprints to facilitate the scoring process

Statistical analysis

The objective was to study and describe the effect (if any) of time/temperature (ADH) on the quality of the fingerprints, with varying age and sex of the donors. Microsoft® Excel for MAC version 16.43 and IBM® SPSS® Statistics version 27 software were used to perform exploratory data analysis and analysis of covariance (ANCOVA). This analysis permitted us to test the main effect and interactions of - age, sex, experimental versus control lightbulbs – (categorical variables) on the quality score (continuous dependent variable), using ADH as the covariate or control variable. The objectives of this analysis were to explore differences in the quality scores among the fixed factors, determine if the interaction between each of the factors was significant based on the significance level of $\alpha = 0.05$ adopted by the discipline (20), and relate ADH to the recoverability of fingerprints in order to determine whether a reliable model fit the data and could estimate time since deposition based on the quality of a recovered fingerprint.

RESEARCH RESULTS & DISCUSSION

Temperatures

The room temperature during the tests and experiments resulted in an average of 24.3 ± 0.01 °C (Table 1). The thermal camera could only be directed at up to ten rectangular areas (used for the tests) or circular points (used for the cohorts) for simultaneous monitoring (Figure 5). Table 2 summarizes several temperatures and related values to be discussed next. Temperature tests were performed on one unlit lightbulb and one lit lightbulb and the temperatures can be seen on Table 2. Using a significance level of $\alpha = 0.05$, student t-tests showed that the mean temperatures for the top and middle regions of each lightbulb were significantly different ($p \leq 0.05$). The lit lightbulb took 2 minutes to reach its highest temperature and 5 minutes to cool down close to room temperature. The cohort's temperature monitoring showed that the top and middle temperatures remained constant for cohort 1, which justified using random points for the rest of the nine cohorts by using three units simultaneously (Figure 6 and Table 3). All the cohort's temperatures for each region were statistically different ($p \leq 0.05$) from each other (Table 3). ADH was calculated averaging the temperature for each region and for each cohort and multiplying it by the number of hours exposed to it (Table 4). These ADH values are more accurate than the ones obtained from the control and heat tests, since they are specific for each cohort. The average room temperature was higher here because up to three units were lit simultaneously instead of one.

Fingerprints

A total of 320 experimental prints and 78 control prints were recovered. One lightbulb was broken during the recovery process, rendering 2 control fingerprints unrecoverable. On the recovered fingerprints, minutiae were marked if present to facilitate the scoring process. Examples of the assigned quality scores to various recovered fingerprints can be seen (Figure 7).

Statistical analysis

Presenting exploratory data analyses on both the experimental and control lightbulbs together did not provide a clear trend, so the results for each of them will be displayed separately. When using boxplots, the reported data will be the interquartile range (IQR) of the quality scores, which accounts for 50% of the data displayed as a box for each variable, on each boxplot. Even though the quality score scale that was used for the impressions consisted of whole numbers from 0 to 5, some IQR's include decimals if the majority of those scores was between two whole numbers. Exploratory data analysis of days lit versus quality scores (QS) for all the donor's experimental lightbulbs (Figure 8) showed that the IQR of the QS's fall between 2-3 for one day lit, between 0-2 for two to four days lit which is a slight decrease, between 0-1 for five days lit which is a second decrease, and then there is a considerable fluctuation of the scores ranging from 0.25-2.75 for eight to ten days lit. The slight decrease from the first day might be explained due to the vaporization of moisture (to which the black powder adheres) over ADH. The variation observed after seven days of ADH cannot yet be explained. It is possible that the lightbulb's heat caused some components of the fingerprint residue to become fixed to its surface, actually helping to preserve minutia. The control lightbulbs trend is different and less accurate, because the lit and unlit lightbulbs where exposed to different ADH and their quality patterns differed (Figure 8).

When analyzing ADH versus quality scores for the experimental lightbulbs (Figure 9), a similar trend from the days lit versus quality scores (Figure 8) was seen. Observing the IQR's, the fingerprint impressions have initial QS's of 2-4 between ADH 2375 and 3144, decrease to QS's of 0-2.5 from ADH 5217 to 14885, slightly increase to QS's of 0.5-2.5 from ADH 16775 to 24295, and then enter to a random fluctuation trend of QS's of 0-3.5 from ADH 26225 to 32749. The most meaningful decreases in QS's occurred around ADH 5217 with QS's of 0-2, and ADH 12389 with QS's of 0-1. The ADH versus quality scores for the control lightbulbs (Figure 9), showed relatively high QS's of 1-5 from ADH 630 to ADH 2092, followed by a decrease in QS's of 1-2 and then random fluctuations. There was also no consistency on any ADH relate to when the highest quality scores where observed for any of the boxplots.

When observing the scatterplot of average quality scores over ADH for the experimental lightbulbs and the control lightbulbs (Figure 10), the most recurrent QS was 2. Using the quality scale of zero to five, a value of two only has definitive ridge flow and debatable minutiae, which may not be helpful at all when latent print examiners perform fingerprint comparisons. For the experimental lightbulbs, the QS started at 3, showed two meaningful decreases and then became random. Also, after the second decrease in quality around 12000 ADH the scores seemed to remain constant between 1 and 2, but that is not what we have seen from the previous boxplots. It is possible that this scatterplot is canceling the random increases and decreases of the quality scores, that then appear to remain constant. For the control lightbulbs the QS started around 3-4, showed one decrease and then became random.

When analyzing ADH versus quality scores for the experimental lightbulbs for the two age categories (Figure 11), the donors aged < 40 years started with IQR of QS's of 2-3 on ADH 2375, while those > 40 years started with slightly higher QS's of 2.5-4. Also, the IQR's were smaller for < 40 years and bigger for > 40 years. For the ADH versus quality scores for the control lightbulbs for the two age categories (Figure 12), the donors aged < 40 years also started with IQR of QS's of 2-3 on ADH 630, while those > 40 years started with slightly higher QS's of 2-4. Also, for the < 40 years donors their IQR's were more accurate than those for the > 40 years donors.

When analyzing ADH versus quality scores for the experimental lightbulbs for the two sex categories (Figure 13) male donors started with slightly high IQR's of QS's of 2.5-4 when compared to females, with QS's of 2-3.5. Both sex categories showed low QS's of 0-1 on ADH 12389. Female donors showed a uniform trend of the QS's around 0-2 from ADH 17395 forward, while the male donors showed more random QS's of 0.5-5. Lastly, female donors showed an increase in quality around ADH 10457 and 16775, which is not seen on male donors. There was no consistency with regard to the relationship among ADH, sex or age category and when the highest scores (4 to 5) were obtained. For the ADH versus quality scores for the control lightbulbs for the two sex categories (Figure 14), again male donors started with slightly higher QS's of 2-4 and females started with QS's of 2-3. Also, the female's trends have more fluctuations between increasing and decreasing IQR's, while the males showed more uniform trends.

ANCOVA

Multiple ANCOVA's were performed to the experimental lightbulbs data, the control lightbulbs data and both the experimental and control lightbulbs data. A significance level of $\alpha = 0.05$ was used. For the experimental lightbulbs (Table 5), there was no effect of sex, age or ADH over the quality scores because all the p-values were over the threshold ($p > 0.05$). For the control lightbulbs (Table 6), the variable sex was significant ($p \leq 0.001$), so there were differences in impression quality between males and females. However, age and ADH were not significant because their the p-values were over the threshold ($p > 0.05$). For both the experimental versus control lightbulbs

(Table 7), the variable sex was significant ($p \leq 0.001$), so there were differences in impression quality between males and females. Similarly, control versus experimental lightbulbs was significant ($p \leq 0.001$), so there were differences between the experimental (lit) and control (unlit) bulbs. However, age was not significant ($p \leq 0.242$) and the covariate ADH was also not significant in the model ($p \leq 0.281$).

CONCLUSION

The objective of this research project was to understand the effect of time and temperature on latent fingerprints quality deposited on glass, when considering multiple donors age and sex variability. Latent fingerprint impressions demonstrated to start with a relatively high quality soon after deposition, followed by a decrease and then random fluctuations over ADH. The high quality observed during the initial ADH's is believed to be due to the impression's high moisture composition, which adhered to the black powder used to recover the print. The decrease in quality may occur because the impression moisture starts to vaporize, making it harder for the black powder to adhere to the print. The fluctuations seen at the end of the explored ADH's cannot be explained and we can only assume it is possible that the originally deposited print was richer in some components that got fixed to the lightbulb early on, fixing the print on the lightbulb surface. There was no consistency about on what variable the highest scores (4 to 5) were obtained. The statistical analysis of covariance showed that sex categories and control versus experimental lightbulbs do have a significant effect on the latent impression's quality, but not ADH and age categories.

For now, this research supports what latent print examiners have intuitively known for some time – that one cannot determine the age of a latent print by visual assessment alone. More research is still needed to give forensic scientists a broader understanding of how latent fingerprints are affected by environmental conditions and donor variability, which can be crucial in court for criminal cases with important impression evidence. Future studies may be able to incorporate other variables, including different substrates, more donors from different ethnicities, different heat conditions that may be achieved using an oven, and even different room temperature conditions to track latent fingerprint quality under different parameters.

REFERENCES

1. Alcaraz-Fossoul J, Patris CM, Muntaner AB, Feixat CB, Badia MG. Determination of latent fingerprint degradation patterns-a real fieldwork study. Int J Legal Med 2012;127(4):857-870. doi: 10.1007/s00414-012-0797-0.
2. Alcaraz-Fossoul J, Patris CM, Feixat CB, McGarr L, Brandelli D, Stow K, et al. Latent Fingermark Aging Patterns (Part I): Minutiae Count as One Indicator of Degradation. J Forensic Sci 2016;61(2):322-333. doi: 10.1111/1556-4029.13007.
3. Alcaraz-Fossoul J, Feixat CB, Tasker J, McGarr L, Stow K, Carreras-Marin C, et al. Latent Fingermark Aging Patterns (Part II): Color Contrast Between Ridges and Furrows as One Indicator of Degradation. J Forensic Sci 2016;61(4):947-958. doi: 10.1111/1556-4029.13099.
4. Colella O, Miller M, Boone E, Buffington-Lester S, Curan III F, Simmons T. The Effect of Time and Temperature on the Persistence and Quality of Latent Fingerprints Recovered from 60-Watt Incandescent Light Bulbs. J Forensic Sci 2020;65(1):90-96. doi: 10.1111/1556-4029.14133.
5. Hinners P, Thomas M, Lee YJ. Determining Fingerprint Age with Mass Spectrometry Imaging via Ozonolysis of Triacylglycerols. Anal Chem 2020;92(4):3125-3132. doi: 10.1021/acs.analchem.9b04765.
6. Zenebe DM, Matti L. Investigation on nature of waste heat from incandescent light bulbs. Proceedings of the 2011 10th International Conference on Environment and Electrical Engineering; 2011; Rome; 1-4.

7. Environmental Protection Agency. How the Energy Independence and Security Act of 2007 Affects Light Bulbs. https://www.epa.gov/cfl/how-energy-independence-and-security-act-2007-affects-light-bulbs (accessed May 20, 2020).
8. BBC News. US lifts ban on old-style light bulbs. https://www.bbc.com/news/world-us-canada-49591143 (accessed May 20, 2020).
9. The New York Times. New York Seeks Computer's Help for fast Fingerprint Identification. https://www.nytimes.com/1985/10/07/nyregion/new-york-seeks-computer-s-help-for-fast-fingerprint-indentification.html (accessed November 13, 2020).
10. The Free Press. Crime spree solved with fingerprint. https://www.mankatofreepress.com/news/local_news/crime-spree-solved-with-fingerprint/article_725ff26b-3738-569a-bd87-8612f03ab5cb.html (accessed November 13, 2020).
11. Rohrig B. Guilty or innocent? ChemMatters 2016;5-7.
12. Shetage SS, Traynor MJ, Brown M, Raji M Graham-Kalio D, Chilcott R. Effect of ethnicity, gender and age on the amount and composition of residual skin surface components derived from sebum, sweat and epidermal lipids. Skin Research and Technology 2014;20:97-107. doi: 10.1111/srt.12091.
13. Modi SK, Elliott SJ, Whetsone J. Impact of Age Groups on Fingerprint Recognition Performance. IEEE Workshop on Automatic Identification Advanced Technologies. 2007:19-23. doi: 10.1109/AUTOID.2007.380586.
14. Galbally J, Haraksim R, Beslay L. A Study of Age and Ageing in Fingerprint Biometrics. IEEE Transactions on Information Forensics and Security. 2019;14(5):1351-1365. doi: 10.1109/TIFS.2018.2878160.

15. Gnanasivam P, Vijayarajan R. Gender Classification from Fingerprint Ridge Count and Fingertip Size using Optimal Score Assignment. Complex Intell Syst 2019;5:343-352. doi: 10.1007/s40747-019-0099-y.

16. Soanboon P, Nanakorn S, Kutanan W. Determination of sex difference from fingerprint ridge density in northeastern Thai teenagers. Egypt J Forensic Sci 2015;6(2):185-193. doi: 10.1016/j.ejfs.2015.08.001.

17. National Institute of Justice. Forensic Science Technology Working Group Operation Requirements, 2016. https://nij.ojp.gov/sites/g/files/xyckuh171/files/media/document/ 2016-forensic-twg-table.pdf (accessed May 27, 2020).

18. SWGFAST Scientific Working Group on Friction Ridge Analysis, Study and Technology. Message from the SWGFAST Chair. http://clpex.com/swgfast/ (accessed May 27, 2020).

19. Materese R. NIST (National Institute of Standards and Technology). Fingerprint and Pattern Evidence. https://www.nist.gov/topics/fingerprints-and-pattern-evidence (accessed May 30, 2020).

20. Chapman W, Hicklin A, Kiebuzinski G, Komarinski P, Mayer-Splain J, Wallner R. Markup Instructions for Extended Friction Ridge Features. Rotterdam, NY. National Institute of Standards and Technology, 2013 Jan. Special Publication (NIST SP) - 1151.

21. National Institute of Justice. Impression and Pattern Evidence. https://nij.ojp.gov/topics/forensics/impression-and-pattern-evidence (accessed May 30, 2020).

22. Taylor S, Dutton E, Aldrich P, Dutton B. Application of Spatial Statistics to Latent Print Identifications: Towards Improved Forensic Science Methodologies. Monmouth, OR. Western Oregon University, 2012 Dec. Report No.: 240590.

<table>
<tr><th></th><th></th><th></th><th>Ridge flow</th><th>Minutiae</th><th>Dots</th><th>Incipients</th><th>Ridge edge features</th><th>Pores</th></tr>
<tr><td>Black</td><td>0</td><td>Background</td><td colspan="6">✗</td></tr>
<tr><td>Red</td><td>1</td><td>Debatable ridge flow</td><td>?</td><td colspan="5">✗</td></tr>
<tr><td>Yellow</td><td>2</td><td>Definitive ridge flow, debatable minutiae</td><td>✓</td><td>?</td><td colspan="4">✗</td></tr>
<tr><td>Green</td><td>3</td><td>Definitive minutiae, debatable ridge edges</td><td colspan="2">✓</td><td colspan="3">?</td><td>✗</td></tr>
<tr><td>Blue</td><td>4</td><td>Definitive ridge edges, debatable pores</td><td colspan="5">✓</td><td>?</td></tr>
<tr><td>Aqua</td><td>5</td><td>All features definitive</td><td colspan="6">✓</td></tr>
</table>

✓	Definitive and unambiguous	Presence, absence, and location are definitive. Contradictory presence or absence of definitive features in a comparison is cause for exclusion.
?	Debatable or ambiguous	Features may be marked, but presence, absence, and location are debatable. Corresponding/contradictory features in a comparison are supporting evidence for individualization/exclusion.
✗	Not discernible or unreliable	Features should not be marked and are ignored if present. No evidence for individualization or exclusion in a comparison exists.

Figure 1: “Ridge Quality Map Values and Their Relation to Feature Confidence” tables, extracted from the “Markup Instructions for Extended Friction Ridge Features” NIST publication, page 21 (18).

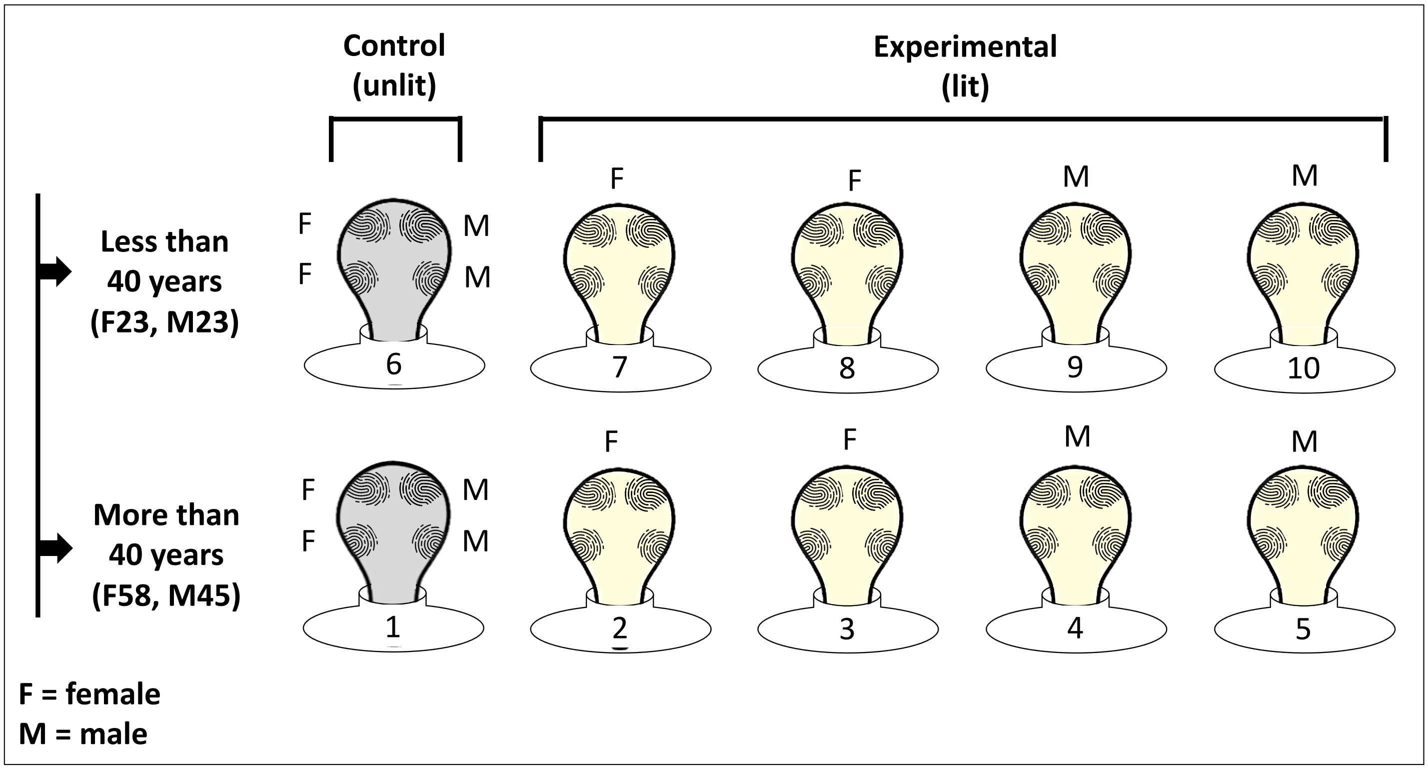


Figure 2: Scheme of lightbulbs distribution per cohort.

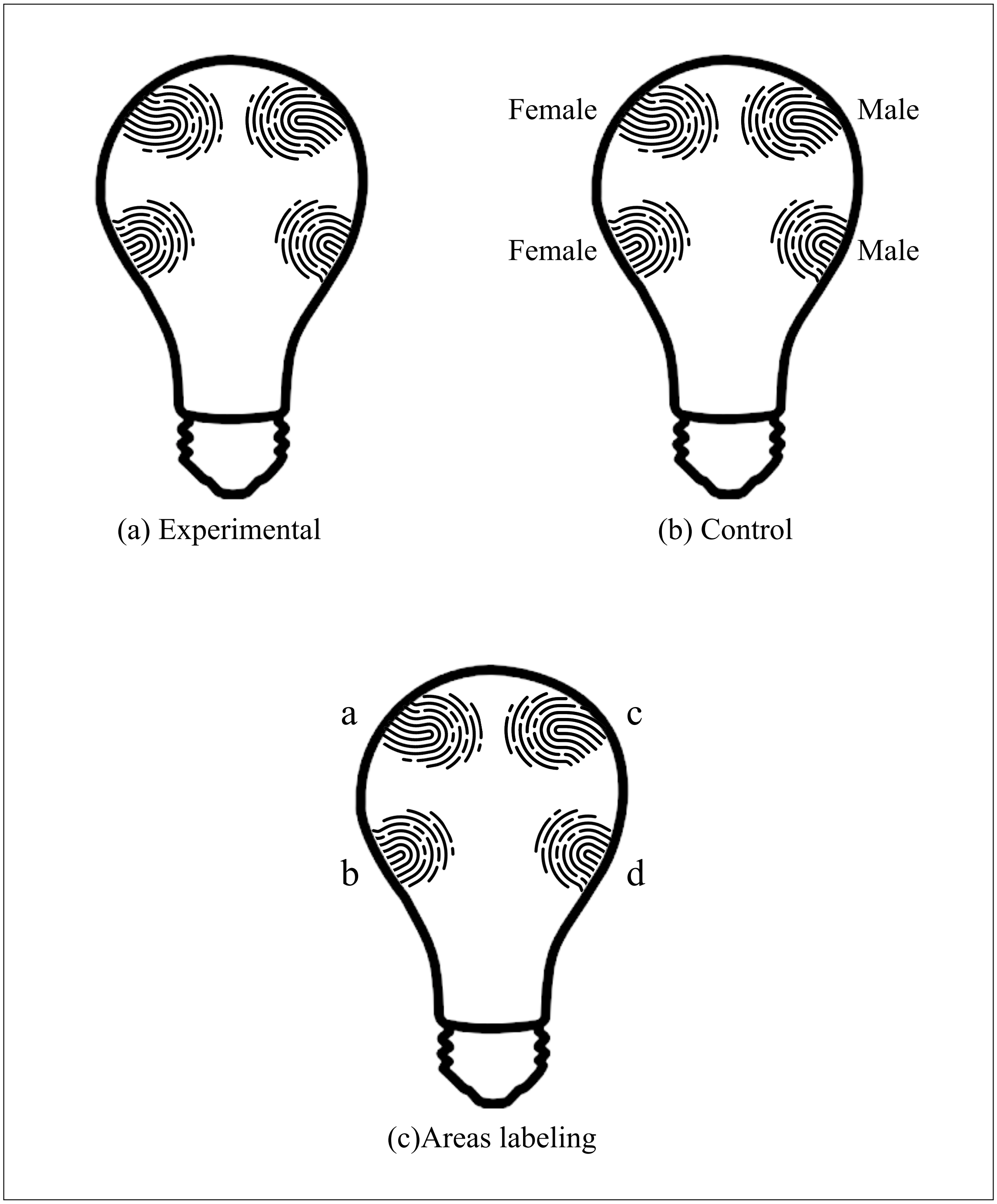


Figure 3: Distribution of donor's fingerprints for the (a) experimental lightbulbs, either female or male, (b) control lightbulbs and (c) areas labeling for the fingerprint recovery process.

Figure 4: Units A, B and C setup, as used on Colella's study.

Table 1: Room temperatures during tests, experimentation and their average

Room temperatures	
Tests	23.85 ± 0.01 °C
Experiment	24.30 ± 0.02 °C
Average	24.30 ± 0.01 °C

Table 2: Lightbulbs average temperatures during the tests for the top and middle regions, p-values and number of samples (n)

Tests temperatures			
Control	Top	28.00 ± 0.04 °C	p-value = 8.8 E-45 n = 64
	Middle	27.10 ± 0.03 °C	
Experimental	Top	128.6 ± 0.2 °C	p-value = 7.9 E-112 n = 96
	Middle	98.1 ± 0.1 °C	
Heat up	Top	130.0 ± 1 °C	
	Middle	98.9 ± 1 °C	
Cool down	Top	30.4 ± 1 °C	
	Middle	30.2 ± 1 °C	

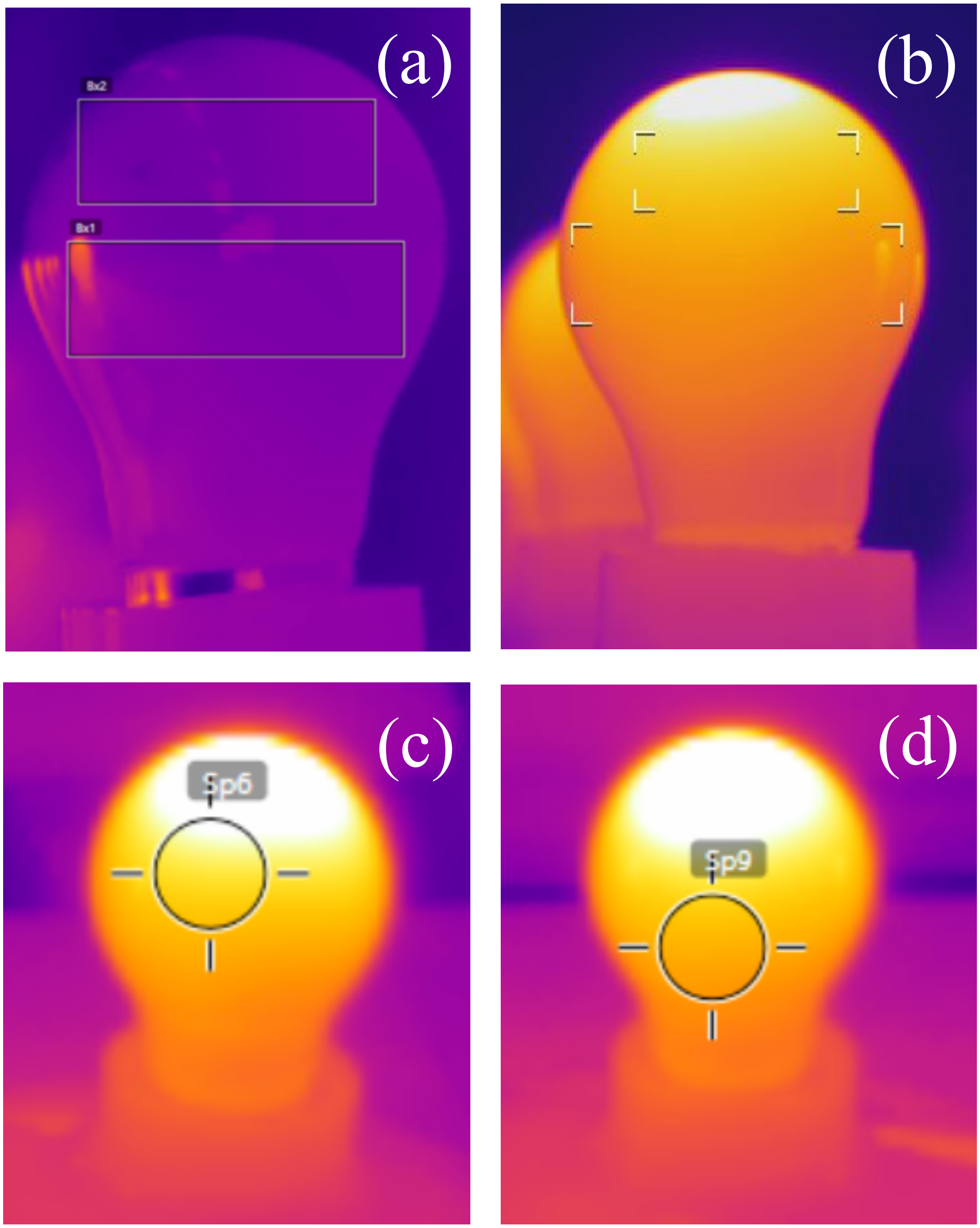


Figure 5: Rectangular areas monitored on the (a) unlit and (b) lit test lightbulbs. Circular points monitored on the cohorts (c) top and (d) middle regions.

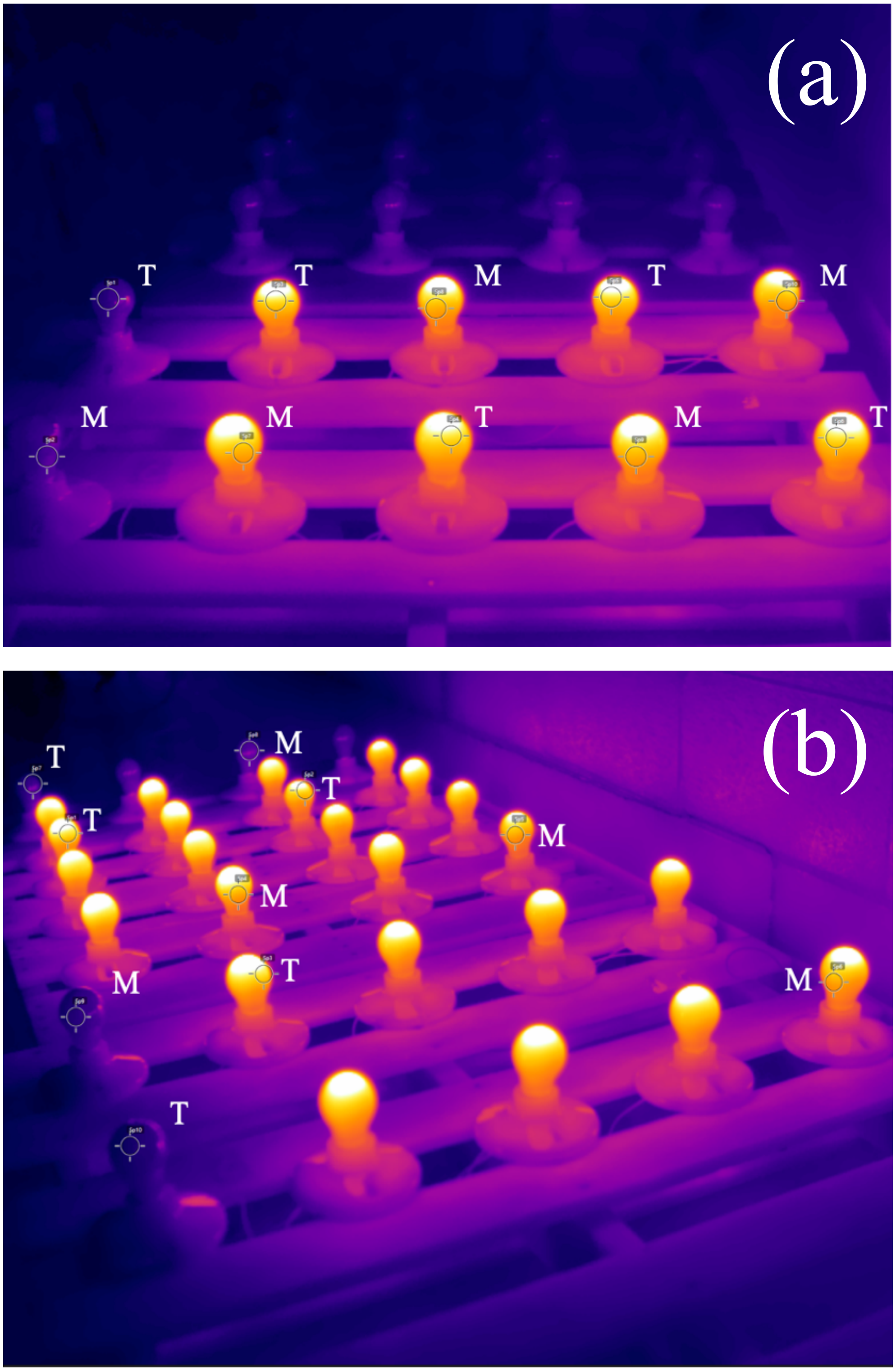


Figure 6: Temperature monitoring setups for (a) Cohort 1 and (b) Cohorts 2-10. The abbreviations T = top and M = middle.

Table 3: Average temperature for each region, standard deviation, number of samples (n), and p-value for the corresponding t-test between regions of the same lightbulb for each cohort

<table>
<tr><th>Cohort</th><th>Lightbulb and region</th><th>Average temperature (°C)</th><th>Standard deviation</th><th>n</th><th>p-value</th></tr>
<tr><td rowspan="4">1</td><td>Exp. Top</td><td>132.1</td><td>1.2</td><td>412</td><td rowspan="2">0</td></tr>
<tr><td>Exp. Middle</td><td>99.7</td><td>1</td><td>412</td></tr>
<tr><td>Ctl Top</td><td>26.2</td><td>0.1</td><td>96</td><td rowspan="2">1.6 E-133</td></tr>
<tr><td>Ctl Middle</td><td>27.6</td><td>0.2</td><td>96</td></tr>
<tr><td rowspan="4">2</td><td>Exp. Top</td><td>141.0</td><td>1.4</td><td>576</td><td rowspan="2">0</td></tr>
<tr><td>Exp. Middle</td><td>108.7</td><td>2.7</td><td>576</td></tr>
<tr><td>Ctl Top</td><td>27.5</td><td>0.6</td><td>384</td><td rowspan="2">4.9 E-77</td></tr>
<tr><td>Ctl Middle</td><td>29.5</td><td>1.6</td><td>384</td></tr>
<tr><td rowspan="4">3</td><td>Exp. Top</td><td>140.8</td><td>1.3</td><td>768</td><td rowspan="2">0</td></tr>
<tr><td>Exp. Middle</td><td>108.7</td><td>2.4</td><td>768</td></tr>
<tr><td>Ctl Top</td><td>27.3</td><td>0.6</td><td>576</td><td rowspan="2">1.0 E-78</td></tr>
<tr><td>Ctl Middle</td><td>29.1</td><td>1.7</td><td>480</td></tr>
<tr><td rowspan="4">4</td><td>Exp. Top</td><td>140.6</td><td>1.4</td><td>864</td><td rowspan="2">0</td></tr>
<tr><td>Exp. Middle</td><td>108.9</td><td>2.4</td><td>864</td></tr>
<tr><td>Ctl Top</td><td>27.0</td><td>0.8</td><td>672</td><td rowspan="2">1.3 E-54</td></tr>
<tr><td>Ctl Middle</td><td>28.5</td><td>2</td><td>576</td></tr>
<tr><td rowspan="4">5</td><td>Exp. Top</td><td>139.8</td><td>4.4</td><td>1437</td><td rowspan="2">0</td></tr>
<tr><td>Exp. Middle</td><td>103.2</td><td>3.4</td><td>1437</td></tr>
<tr><td>Ctl Top</td><td>28.0</td><td>1.1</td><td>958</td><td rowspan="2">5.6 E-129</td></tr>
<tr><td>Ctl Middle</td><td>30.0</td><td>2.4</td><td>958</td></tr>
<tr><td rowspan="4">6</td><td>Exp. Top</td><td>140.0</td><td>4.4</td><td>1629</td><td rowspan="2">0</td></tr>
<tr><td>Exp. Middle</td><td>103.4</td><td>3.2</td><td>1629</td></tr>
<tr><td>Ctl Top</td><td>27.8</td><td>1.1</td><td>1150</td><td rowspan="2">6.3 E-129</td></tr>
<tr><td>Ctl Middle</td><td>29.8</td><td>2.4</td><td>1054</td></tr>
</table>

Abbreviations: Exp = experimental; Ctl = control.

Table 3 (continued): Average temperature for each region, standard deviation, number of samples (n), and p-value for the corresponding t-test between regions of the same lightbulb for each cohort

Cohort	Lightbulb and region	Average temperature (°C)	Standard deviation	n	p-value
7	Exp. Top	140.2	4.3	1725	0
	Exp. Middle	103.5	3.2	1725	
	Ctl Top	27.6	1.2	1246	5.7 E-101
	Ctl Middle	29.4	2.4	1150	
8	Exp. Top	136.6	1.9	2301	0
	Exp. Middle	101.3	2	2301	
	Ctl Top	28.2	1	1534	5.5 E-217
	Ctl Middle	30.0	1.7	1534	
9	Exp. Top	136.5	2	2493	0
	Exp. Middle	101.3	2	2493	
	Ctl Top	28.2	0.9	1630	3.6 E-247
	Ctl Middle	30.0	1.7	1630	
10	Exp. Top	136.5	1.9	2589	0
	Exp. Middle	101.2	2	2589	
	Ctl Top	28.2	0.9	1726	1.9 E-262
	Ctl Middle	30.0	1.7	1630	

Abbreviations: Exp = experimental; Ctl = control.

Table 4: ADH calculations for the top and middle regions of the control and experimental lightbulbs, for cohorts 1 to 10

Experimental lightbulbs					
Cohort	**Hours**	**Average temperature (°C)**		**ADH**	
		Top	**Middle**	**Top**	**Middle**
1	24	131.0	99.0	3144	2375
2	48	141.0	108.7	6766	5217
3	72	140.8	108.7	10135	7830
4	96	140.6	108.9	13494	10457
5	120	139.8	103.2	16775	12389
6	144	140.0	103.4	20164	14885
7	168	140.2	103.5	23546	17395
8	192	136.6	101.3	26225	19458
9	216	136.5	101.3	29477	21874
10	240	136.5	101.2	32749	24295
Control lightbulbs					
Cohort	**Hours**	**Average temperature (°C)**		**ADH**	
		Top	**Middle**	**Top**	**Middle**
1	24	26.2	27.6	630	663
2	48	27.5	29.5	1321	1415
3	72	27.3	29.1	1965	2092
4	96	27.0	28.5	2597	2736
5	120	28.0	30.0	3356	3602
6	144	27.8	29.8	4005	4287
7	168	27.6	29.4	4641	4941
8	192	28.2	30.0	5415	5753
9	216	28.2	30.0	6095	6484
10	240	28.2	30.0	6757	7205

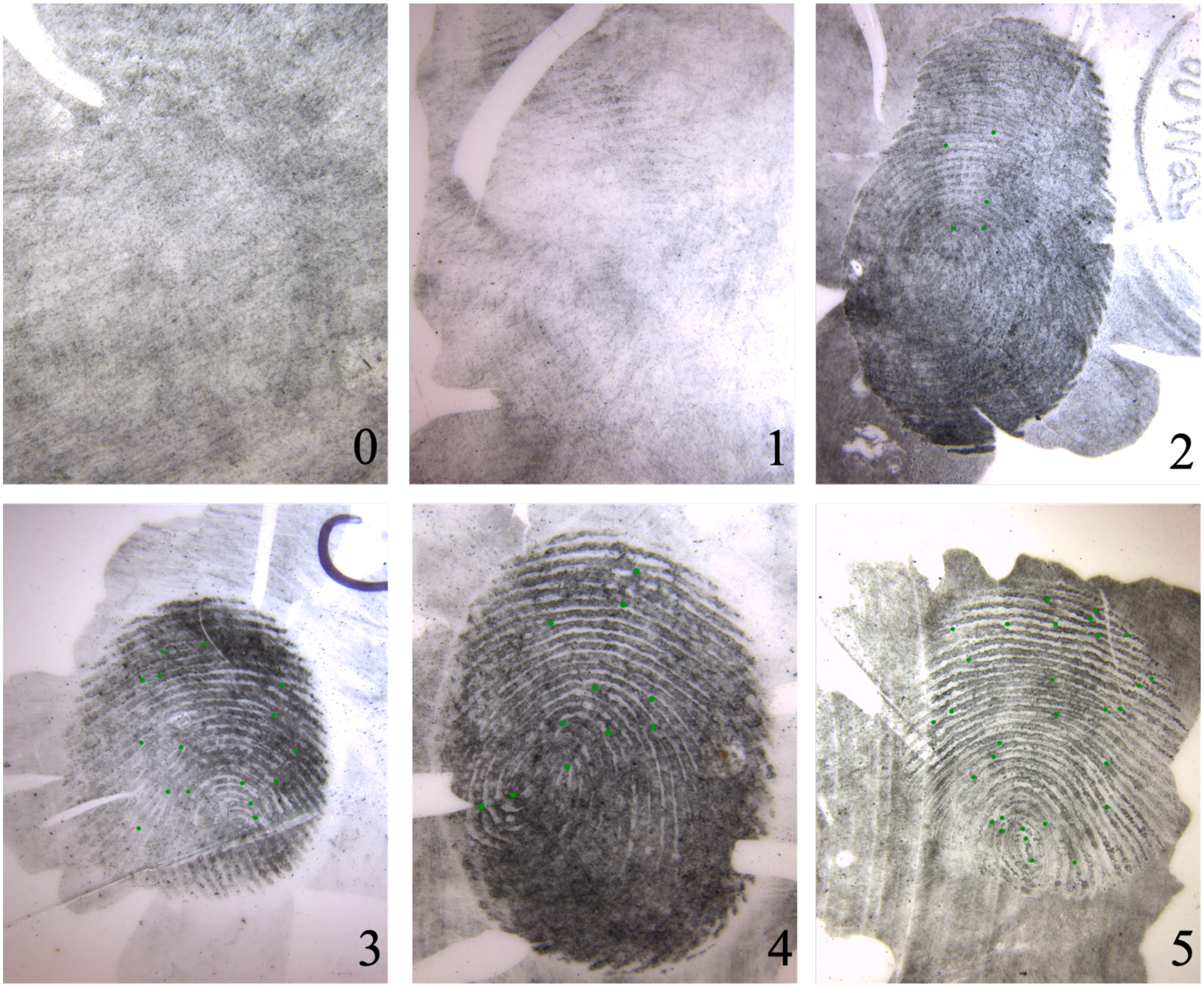


Figure 7: Examples of the assigned quality scores to various recovered latent fingerprints impressions during the experiment.

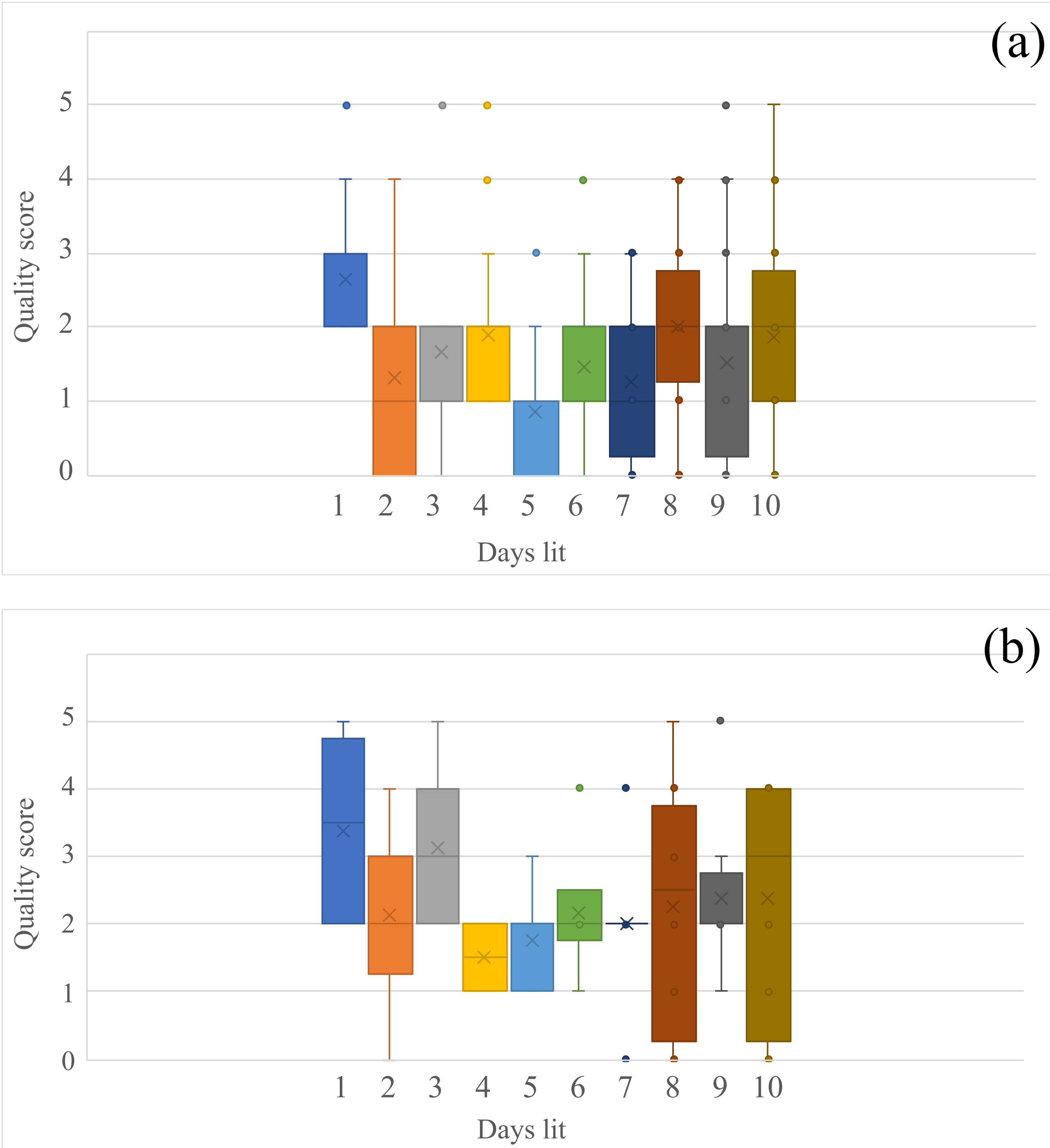


Figure 8: Boxplots of days lit versus quality score for all the donors, for (a) experimental and (b) control lightbulbs.

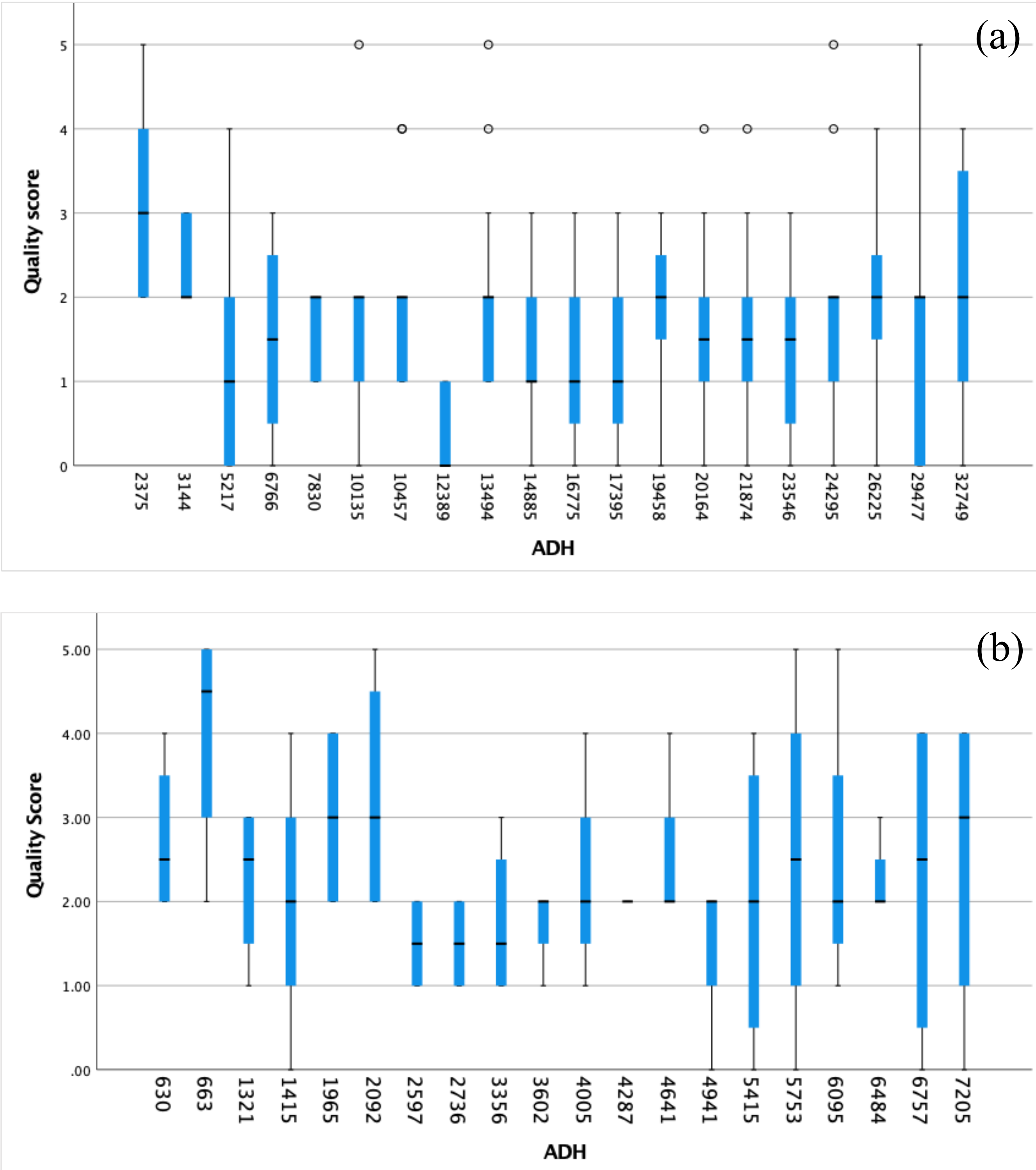


Figure 9: Boxplots of ADH versus quality scores for all the donors, for (a) experimental and (b) control lightbulbs.

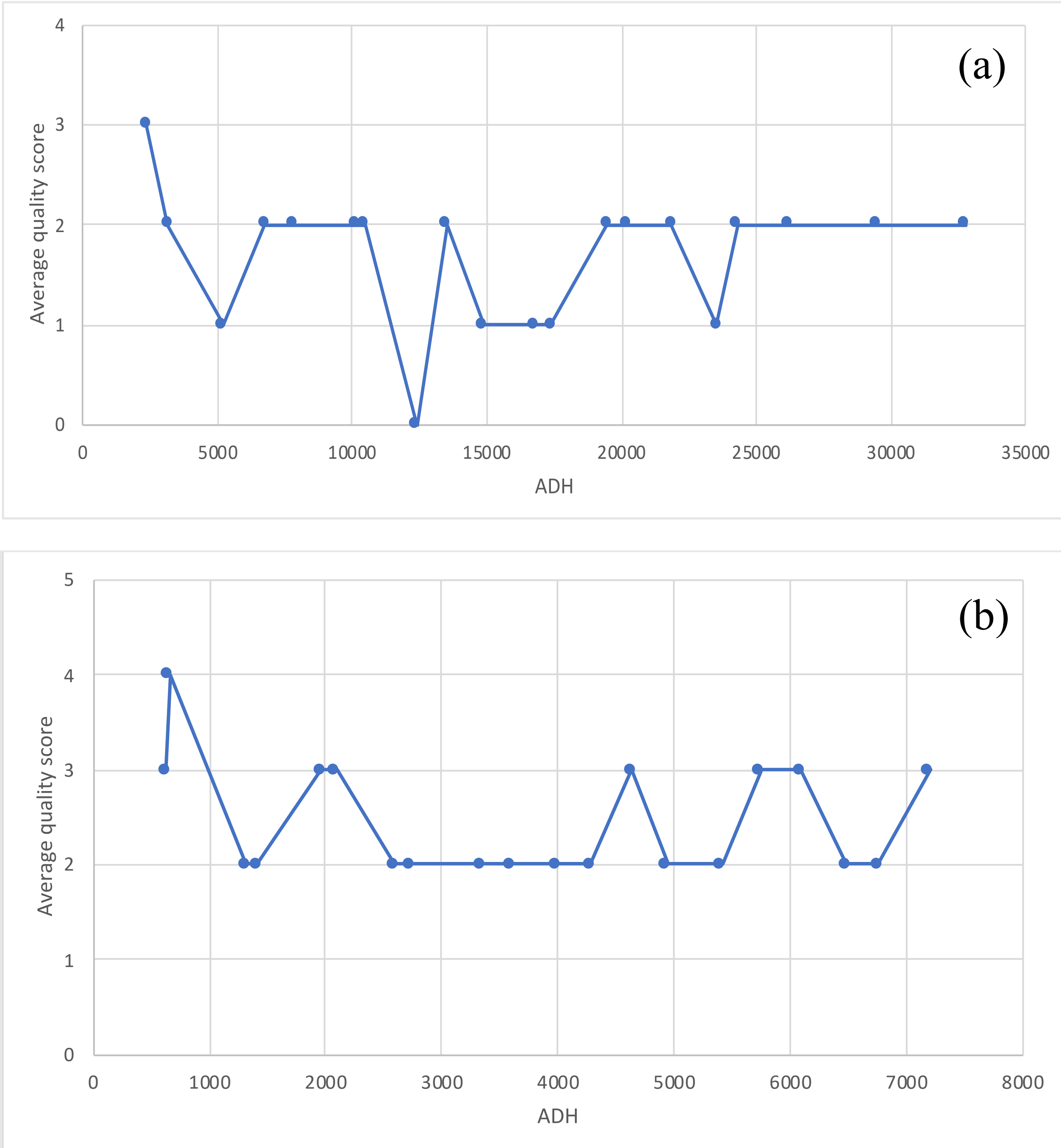


Figure 10: Scatterplots with lines of the average quality scores over ADH for all the donors, for (a) experimental and (b) control lightbulbs.

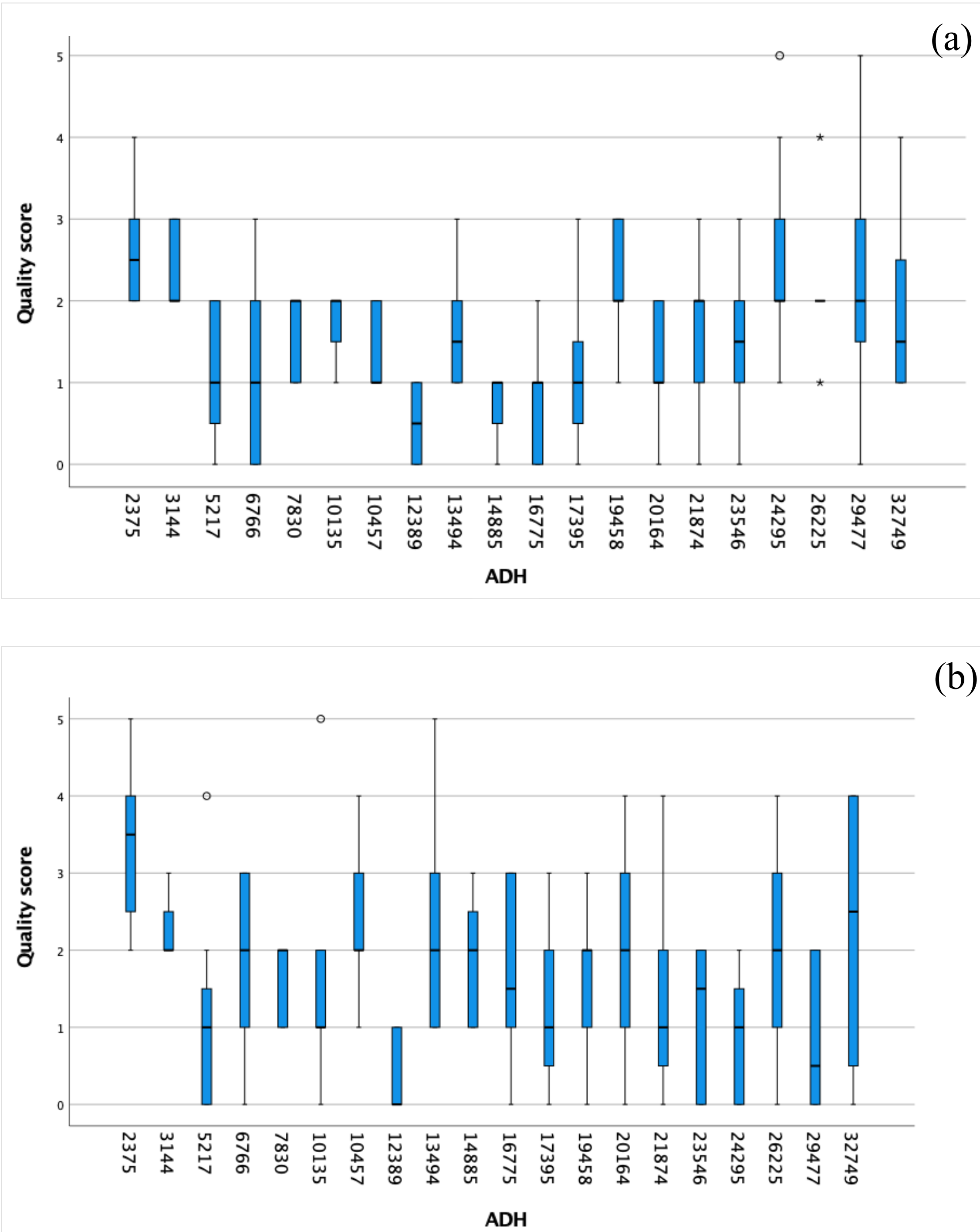


Figure 11: Boxplots of ADH versus quality scores for the experimental lightbulbs, for the age categories of (a) < 40 years and (b) > 40 years.

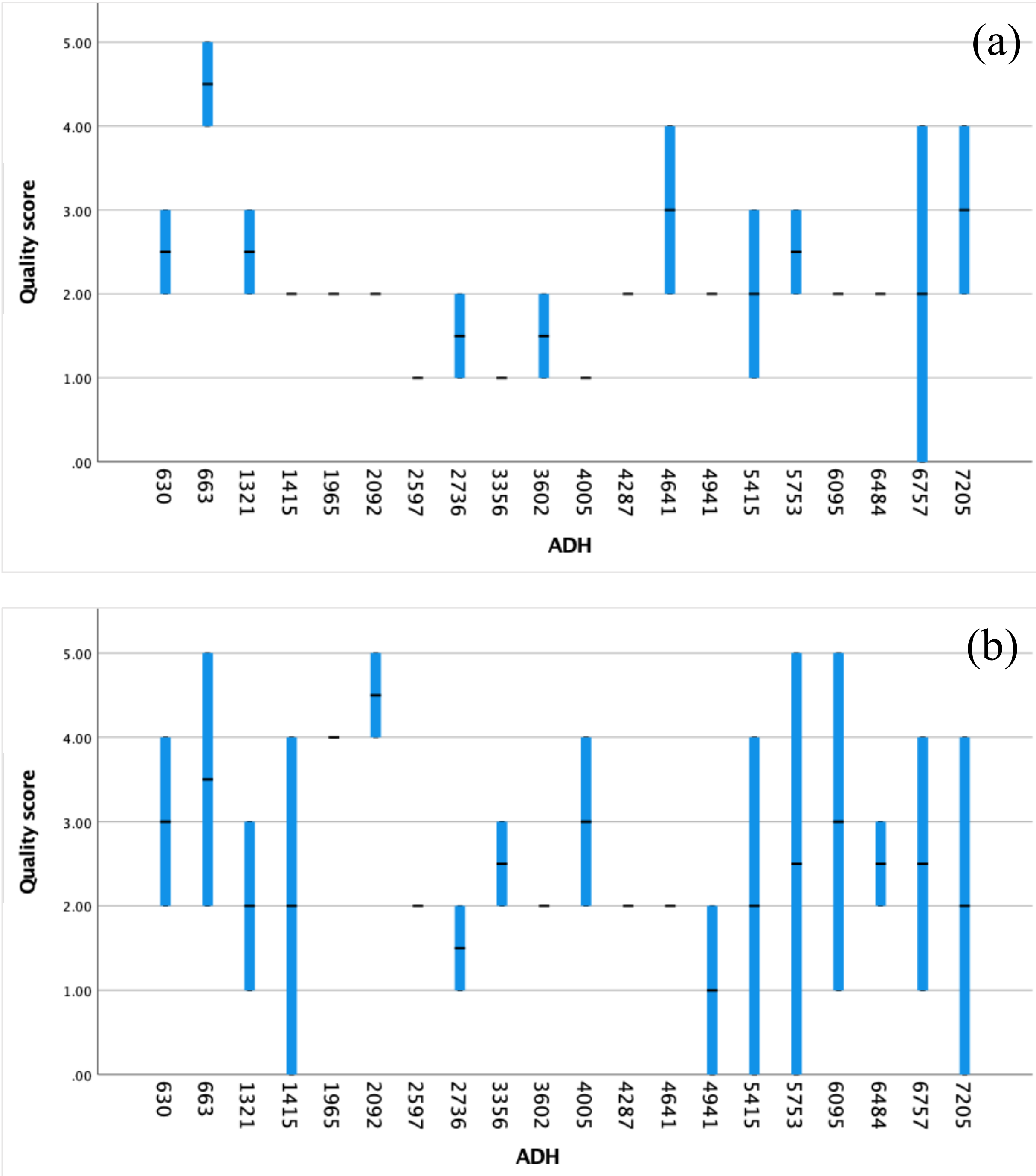


Figure 12: Boxplots of ADH versus quality scores for the control lightbulbs, for the age categories of (a) < 40 years and (b) > 40 years.

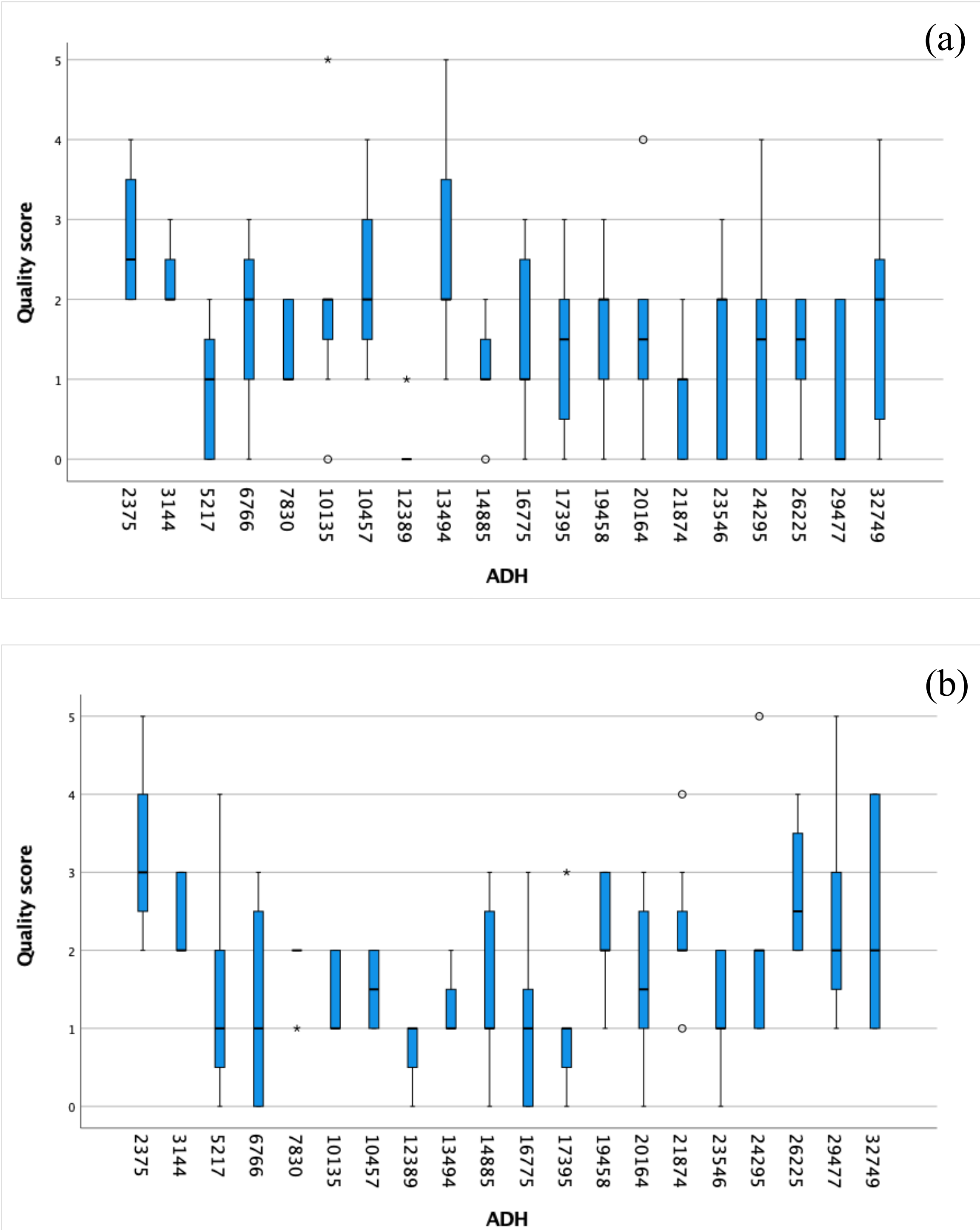
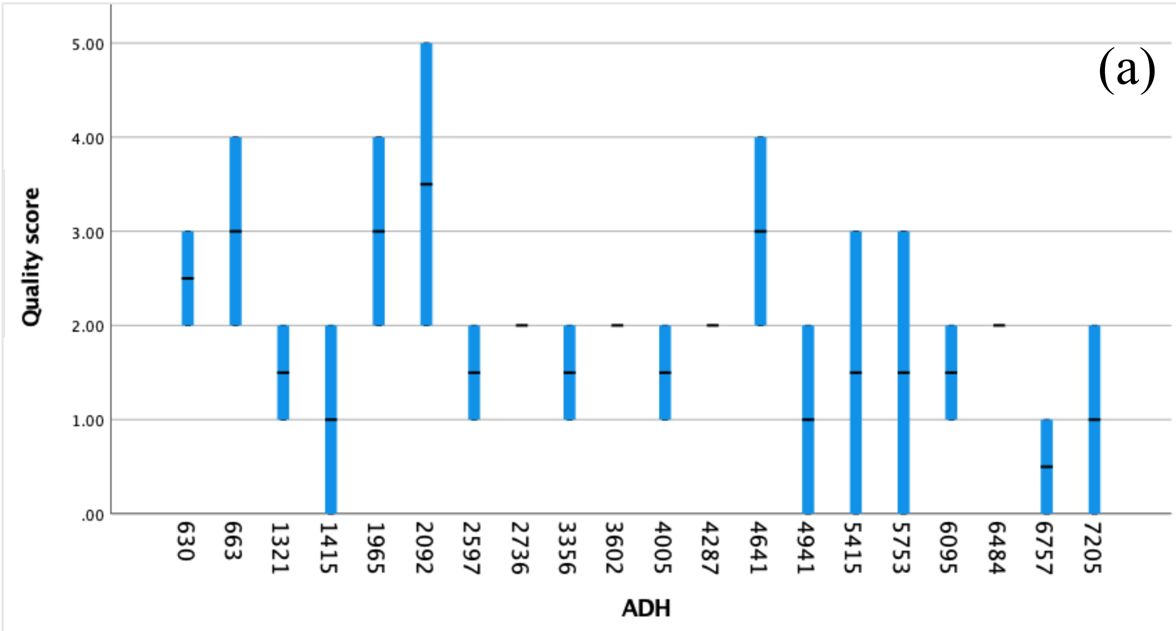


Figure 13: Boxplots of ADH versus quality scores for the experimental lightbulbs, for the sex categories of (a) female and (b) male donors.



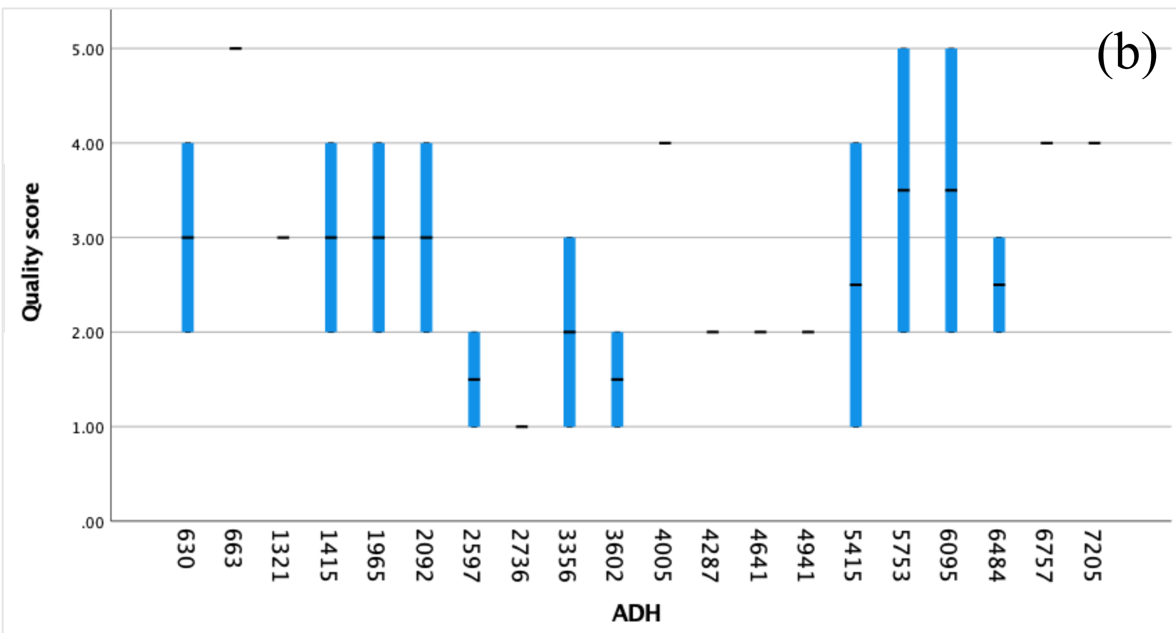


Figure 14: Boxplots of ADH versus quality scores for the control lightbulbs, for the sex categories of (a) female and (b) male donors.

Table 5: Results for the analysis of covariance for the experimental lightbulbs, performed using the SPSS Statistics software.

Tests of Between-Subjects Effects

Dependent Variable: QUALITYSCORE

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6.291[a]	3	2.097	1.646	.179
Intercept	222.426	1	222.426	174.621	.000
ADH	1.166	1	1.166	.915	.339
AGE	.613	1	.613	.481	.489
SEX	4.513	1	4.513	3.543	.061
Error	402.509	316	1.274		
Total	1280.000	320			
Corrected Total	408.800	319			

a. R Squared = .015 (Adjusted R Squared = .006)

Table 6: Results for the analysis of covariance for the control lightbulbs, performed using the SPSS Statistics software.

Tests of Between-Subjects Effects

Dependent Variable: QSctl

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	21.356[a]	3	7.119	4.735	.004
Intercept	121.922	1	121.922	81.091	.000
agectl	2.000	1	2.000	1.330	.253
sexctl	16.826	1	16.826	11.191	.001
ADHctl	2.176	1	2.176	1.447	.233
Error	111.260	74	1.504		
Total	548.000	78			
Corrected Total	132.615	77			

a. R Squared = .161 (Adjusted R Squared = .127)

Table 7: Results for the analysis of covariance for both the experimental and control lightbulbs, performed using the SPSS Statistics software.

Tests of Between-Subjects Effects

Dependent Variable: QS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	44.504[a]	4	11.126	8.344	.000
Intercept	525.155	1	525.155	393.837	.000
SEX	13.936	1	13.936	10.451	.001
AGE	1.833	1	1.833	1.374	.242
ADH	1.554	1	1.554	1.166	.281
CTLvsEXP	14.280	1	14.280	10.709	.001
Error	524.039	393	1.333		
Total	1828.000	398			
Corrected Total	568.543	397			

a. R Squared = .078 (Adjusted R Squared = .069)

VITA

Kinaysha Mar Collazo Maldonado B.S. was born on August 17, 1996, in Bayamón, Puerto Rico, and is an American citizen. She completed her high school in 2013 at the Central Visual Arts School, where she also earned an Architectural Design diploma. She earned her bachelor's degree in Chemistry on 2019 at the University of Puerto Rico, Rio Piedras Campus (UPR-RP). Since then, she has been a member of the American Chemical Society, the National Society of Collegiate Scholars and the Golden Key International Honour Society. She participated from various research projects and internships in chemistry, biochemistry and electrochemistry. She also became a member of the American Chemical Society (ACS) Student Chapter, where she served as member, board of directors' member, activities coordinator and president. She was also chosen as an ACS Scholar from 2015-2019 and as a NASA Puerto Rico Space Grant Consortium Fellow in 2015.

In 2019, she was admitted to the Virginia Commonwealth University Master's program in Forensic Science with a track on Physical Analysis. At the VCU Department of Forensic Science she volunteers to support community service activities and inspire others to get involved in STEM. She earned the 2020 Emily R. Murphy Scholarship in Forensic Science and the 2020 Association for Firearms and Tool Mark Examiners (AFTE) Scholarship. After pursuing her master's degree, she plans on working in a criminalistics, to analyze physical evidence and support criminal investigations.